Middle Ear Barotrauma in Student Pilots

Jung Heob Sohn; Kyoung Rai Cho

The present study reports the clinical features of middle ear barotrauma in student pilots in the Republic of Korea Air INTRODUCTION: Force. **METHODS:** The authors reviewed medical records of student pilots with barotrauma. The grade of barotrauma was assigned using Teed's classification. This study included nasal symptoms, endoscopic findings of the nasal cavity, and clinical course (duration, recurrence). The relationship between middle ear barotrauma and the nasal airway was also evaluated. There were 57 cases in 51 pilots included. There were 49 cases (86.0%) that showed unilateral disease and 4 subjects RESULTS: experienced relapse. Two subjects (3.9%) had chronic rhinosinusitis and four subjects (7.8%) had allergic rhinitis. Ear fullness was reported in all cases, while hearing loss and persistent ear pain were reported in 3 cases (5.3%) and 19 cases (33.3%), respectively. Stuffy nose (26 cases, 45.6%) and rhinorrhea (24 cases, 42.1%) were relatively common. Most cases were Grade 0 (23 cases, 40.3%) or Grade III (27 cases, 47.4%) according to Teed's classification. Septal deviation was observed in 12 cases (21.0%), while turbinate hypertrophy was seen in 53 cases (93.0%) and increased nasal discharge in 33 cases (57.9%). The grade of barotrauma varied significantly according to the severity of turbinate hypertrophy and nasal discharge. The mean duration of disease was 6.8 d. Nasal symptoms and endoscopic findings showed some association with the grade and duration of barotrauma. Most **DISCUSSION:** cases resolved within a week; however, barotrauma showed persistence or relapse in some cases. barotrauma, middle ear, aerospace medicine, nasal cavity. **KEYWORDS:**

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iddle ear barotrauma is an inflammatory change of the tympanic membrane and middle ear cavity from pressure discrepancies between the middle ear cavity and ambient air, which may occur during aviation, diving, or hyperbaric oxygen therapy.^{12,14} Eustachian tube dysfunction is the most common etiology of middle ear barotrauma,¹⁰ and upper airway diseases, including rhinosinusitis, allergic rhinitis, septal deviation and adeno-tonsillar hypertrophy, are known to increase nasal airway resistance.4,15 Several studies have reported that such nasal pathologies might be risk factors for Eustachian tube dysfunction.9,20,25 Therefore, the nasal airway may influence the pathophysiology of middle ear barotrauma. The reported prevalence of middle ear barotrauma after flight varies from 2 to 17%;²² Morgagni et al. reported that the incidence of middle ear barotrauma in trained aircrews was 2.4%.15

KT-1 (Korea Aerospace Industries, Sacheon, Korea), a singleengine basic training aircraft, is used for intermediate flight training programs in the Republic of Korea Air Force. This model has no pressurization system in the cabin; therefore, student pilots in the course may be at increased risk of middle ear barotrauma. In addition, student pilots are still learning active pressurization maneuvers, so they often perform an incorrect or delayed Valsalva maneuver. Prevention and management of middle ear barotrauma is important for student pilots because a long period of grounding due to persistent ear symptoms may steepen the learning curve in affected student pilots.

Our literature review revealed no other reports on the clinical features of middle ear barotrauma in student pilots. Herein, the authors report the clinical course of middle ear barotrauma in student pilots in the Republic of Korea Air Force. The

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relationship between middle ear barotrauma and the nasal conditions of each subject, including subjective symptoms such as stuffy nose, rhinorrhea, cough, sputum, throat pain and sneezing, and objective nasal endoscopic findings was also estimated in the present study.

METHODS

Subjects

This was a retrospective observational study of middle ear barotrauma in student pilots from July 2009 to August 2010. Pilots who experienced ear fullness or ear pain during flight and visited the aerospace medical corps otolaryngology clinic in the flight training wing were enrolled. After obtaining approval from the Institutional Ethics Committee, clinical data of the subjects were reviewed in this study.

Prior to the flight-training program, all student pilots were instructed to have their eardrum examined by an otolaryngologist and to have their hearing ability checked through pure tone audiometry. Medical records, including the presence of ear, nose, and throat (ENT) disease and history of ear and nasal surgery, were also reviewed. Individuals who were found to have ongoing morbidity that could interrupt flight missions were dropped from the program. Therefore, subjects in the present study were generally healthy and had no evidence of permanent Eustachian tube dysfunction. Training aircraft climbed up to 5486.4 m (18,000 ft) altitude during flight training and flight missions usually took place between 4267.2 m (14,000 ft) and 4876.8 (16,000 ft) altitude. If trainees experienced any discomfort during flight training, they were instructed to suspend the mission and reduce the flight altitude. In the case that their symptoms continued or worsened even after landing, student pilots were told to visit the clinic in the aerospace medical corps.

Procedure

Subjects complaining of ear symptoms (ear fullness, ear pain, tinnitus, otorrhea, or hearing loss) had their eardrums evaluated for middle ear barotrauma with a 0°, 2.7-mm rigid endoscope (Richard Wolf Medical Instr., Vernon Hills, IL) by an otolaryngologist who was also a certified flight surgeon. According to the objective findings of the eardrum, the severity of middle ear barotrauma was categorized using Teed's classification:²³ Grade 0 (no sign of barotrauma), Grade I (retraction of the tympanic membrane with partial redness in Shrapnell's membrane and along the manubrium), Grade II (retraction of the tympanic membrane with total hyperemia), Grade III (hemo-tympanum with or without air fluid level in the middle ear), and Grade IV (rupture of the tympanic membrane). In bilateral cases, the grade of middle ear barotrauma was determined by the findings of the more serious side.

Combined nasal symptoms (stuffy nose, rhinorrhea, cough, sputum, throat pain, and sneezing) during flights were also assessed and the degree of discomfort was rated on a score from 0 to 2 (0, none; 1, mild; 2, moderate to severe). The nasal cavity was inspected with a 30° , 4.0-mm rigid endoscope (Richard

Wolf Medical Instr.) and the presence of septal deviation (right/ left side; none), hypertrophy of the inferior turbinate (0, rigid endoscope can pass without any resistance and middle turbinate is visible; 1, only the anterior border of the middle turbinate can be seen; 2, it is impossible to advance the rigid endoscope through the nasal cavity and no part of the middle turbinate is visible), and the appearance of nasal discharge (0, none; 1, scanty and mucous; 2, large amount and very thick; 3, mucopurulent) were appraised. In addition, a medical history of allergic rhinitis and recurrent rhinosinusitis was also taken.

Symptomatic treatment was given to each subject during illness. Acetaminophen 500 mg and pseudoephedrine 60 mg twice daily were administered orally in accordance with symptoms. Daily surveillance was applied and temporary flying restrictions were imposed on all subjects until middle ear barotrauma improved. Improvement was defined as resolution of symptoms and normalization of the tympanic membrane (normal transparency of the tympanic membrane without any effusion or perforation). After improvement, an additional 2-wk monitoring period was enacted to identify any recurrence after flights were resumed. The duration of illness was designated as the period from diagnosis to the time of improvement of middle ear barotrauma. Subjects who were lost to follow-up were eventually excluded from the present study.

Statistical Analysis

The Cochran-Armitage trend test was used to investigate relationships between the grades of eardrum trauma, combined nasal symptoms, objective findings of the nasal cavity, and duration of illness in cases of middle ear barotrauma. All statistical analyses were performed using R package version 3.2.4 (http://www.r-project.org). The level of significance was set at P < 0.05.

RESULTS

There were 57 cases from 51 pilots (47 men, 4 women) eventually eligible for this study. Two cases (3.4%) were lost to follow-up, so they were excluded. The mean age of the subjects was 24 yr (23 to 26 yr). There were 31 cases (54.4%) that affected the right ear and 18 cases (31.6%) that affected the left ear; 8 cases (14.0%) were bilateral. Four student pilots (three men, one woman) had recurrent middle ear barotrauma (**Table I**). These cases exhibited a 2-wk or longer disease-free period prior to each onset; therefore, each of these 10 incidents (17.5%) was considered a discrete case. Two pilots (3.9%) had a previous history of chronic rhinosinusitis and four subjects (7.8%) had been diagnosed with allergic rhinitis.

All pilots complained of persistent ear fullness (100.0%). Hearing loss was reported in 3 cases (5.3%) and persistent ear pain was observed in 19 cases (33.3%). No subject had otorrhea or tinnitus. Information on combined nasal symptoms for all cases is shown in **Fig. 1**. A stuffy nose was reported in 26 cases (45.6%) and rhinorrhea in 24 cases (42.1%). Sputum was demonstrated in 13 cases (22.8%) and cough in 11 cases (19.3%).

Table I.	Clinical Charact	eristics of Four Su	bjects with R	Recurrent Middle Ea	ir Barotrauma.
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							EAR SYMPTOMS		
	SEX	AGE	PAST HISTORY	INTERVAL (DAYS)	GRADE	DURATION (DAYS)	HEARING LOSS	EAR FULLNESS	EAR PAIN
1	F	23	None	0		22		+	+
				37		2		+	
2	Μ	25	None	0		5		+	
				36		6		+	+
				71		35	+	+	
3	Μ	24	Chronic rhino-sinusitis	0		14		+	+
				65	0	3		+	+
4	Μ	24	Allergic rhinitis	0	0	2		+	
				19		9		+	
				65		3		+	

Interval (days) means the duration of time between the onset of prior and present episodes of middle ear barotrauma in each subject.

Nine subjects (15.8%) complained of throat pain and seven cases (12.3%) reported sneezing.

Using Teed's classification, 23 cases (40.3%) were classified as Grade 0 and 27 (47.4%) as Grade III. Five subjects (8.8%) were Grade I and two (3.5%) with eardrum rupture were classified as Grade IV. Endoscopic findings of the nasal cavity are displayed in Fig. 2. A deviated nasal septum was found in 12 cases (21.0%), 10 cases (17.5%) had right-sided deviation, and 2 cases (3.5%) had left-sided deviation. Hypertrophy of the inferior turbinate was observed in most cases (53 cases, 93.0%). Among the 53 cases with hypertrophy of the inferior turbinate, the score of turbinate hypertrophy was defined as "1" in 21 cases (36.9%), while the score was defined as "2" in 32 cases (56.1%). Increased nasal discharge was seen in 33 cases (57.9%); there were 22 cases (38.6%) with mucous nasal discharge and 10 cases (17.5%) with a large amount of very thick nasal secretion. One pilot (1.8%) had acute bacterial rhinosinusitis with mucopurulent nasal discharge. She was prescribed oral antibiotics (amoxicillin-clavulanate 625 mg, three times daily for 7 d) and improved within a week without recurrence.

The distribution of nasal symptom severity and endoscopic findings according to the grade of middle ear barotrauma are shown in **Table II** and **Table III**. Pilots tended to display more severe stuffy nose and rhinorrhea depending on the barotraumas grade; however, there was no statistical significance for



Fig. 1. Combined nasal symptoms of affected student pilots, including the number and percentage of cases according to the severity of nasal symptoms.

either stuffy nose (T = 1.996, df = 1, P = 0.158) or rhinorrhea (T = 2.640, df = 1, P = 0.104). The presence of septal deviation was not significantly associated with grade (T = 1.824, df = 1, P = 0.177). Meanwhile, the severity of turbinate hypertrophy (T = 5.044, df = 1, P = 0.025) and nasal discharge (T = 8.401, df = 1, P = 0.004) demonstrated a relevant difference in accordance with the grade of the affected eardrum.

The mean duration of illness (the time from diagnosis to improvement of middle ear barotraumas) was 6.8 d (1–60 d, median: 4 d). Without any recurrence, 16 cases (28.1%) improved within 2 d, while 43 cases (75.4%) resolved within a week (**Fig. 3**). The duration of illness was categorized into four groups: group 1 (subjects who were improved within 2 d), group 2 (subjects who were improved within 7 d), and group 4 (disease duration was more than 7 d). Then the categorized data of the disease duration was analyzed with the grade of middle ear barotrauma. There was a tendency to take more time to recover from middle ear barotrauma depending on the grade (T = 11.503, df = 1, P = 0.001). The association between duration and grade of middle ear barotrauma is shown in **Fig. 4**.

One case that took 60 d to completely resolve demonstrated bilateral middle ear trauma with a perforated right tympanic membrane (Grade IV). The left ear drum was completely turbid with an amber-colored effusion and retraction. Nasal endoscopy showed moderate to severe hypertrophy of the inferior turbinate and a large amount of thick nasal secretion. The pilot had no history of other episodes of chronic rhinosinusitis or allergic rhinitis. It initially took 16 d for improvement in subjective symptoms and eardrum findings; however, he reported recurrent ear pain and ear fullness after resuming flight. The left tympanic membrane was retracted and fully turbid with effusion. At first, there was no evidence of recurrent barotrauma in the right eardrum; however, during follow-up, middle ear effusion was present on the right side and retraction of both eardrums had progressed to the promontory of the middle ear.

Methylprednisolone 24 mg daily was administered orally for 7 d and the middle ear effusion disappeared after 15 d. Both the pilot's symptoms and objective findings were entirely resolved 2 mo after initial onset and there were no relapses. Due to the long duration of flight restriction, he failed his training course;



Fig. 2. Distribution of the nasal endoscopic findings for all subjects. DSN: deviation of nasal septum, ITH: hypertrophy of inferior turbinate. For DSN, "0" indicates the absence of septal deviation. Left-sided deviation was designated as "1" and right-sided deviation as "2". The ITH score (0, middle turbinate is fully visible; 1, middle turbinate can be seen partially; 2, no part of the middle turbinate is visible) and nasal discharge (0, none; 1, scanty and mucous; 2, a large amount or very thick; 3, mucopurulent) were graded according to the nasal endoscopy findings.

however, he eventually passed the following course. Another case, which required 35 d for full recovery, was unilateral. The left eardrum was retracted and touched the malleus and no effusion was seen (Grade I). Nasal endoscopic findings exhibited deviation of the nasal septum to the right side, inferior turbinate hypertrophy with a score of 2, and very thick nasal discharge. The pilot did not have a history of chronic rhinosinusitis or allergic rhinitis, but reported two prior episodes of middle ear barotrauma that improved within a week. His eardrum retraction lasted over a month and, similar to the previous case, he also initially failed the flight course, but passed the following course.

DISCUSSION

Ear pain during flight is often regarded as a natural physiological phenomenon. However, cases with eardrum pathology or persistent ear pain or fullness after flight are often diagnosed as middle ear barotrauma, which can occur after changes in barometric pressure.² The reported prevalence of middle ear barotrauma varies,^{1,5,16} but it might be underestimated in Air Force pilots, who tend to avoid reporting discomfort in order to avoid interference with their flight training and career. This study was performed based on clinical features of middle ear barotrauma in student pilots, who were less likely to drop out of follow-up. Therefore, the authors expected to obtain useful information about the management of middle ear barotrauma in aircrews.

Middle ear barotrauma can occur under conditions that interrupt the function of the Eustachian tube or in cases in which the velocity of pressure change exceeds tube competency.⁶ The Eustachian tube, which controls middle ear pressure, acts as a one-way valve, with the proximal cartilaginous portion of the tube collapsing and opening spontaneously when middle ear pressure surpasses ambient pressure.^{11,12} Therefore, active pressurization maneuvers such as yawning, swallowing, or the Valsalva maneuver are required to open the tube for pilots during landing or other changes in altitude.^{8,17,19} An impaired ability to equalize middle ear pressure can increase the pressure differential so that mucosal congestion and hemorrhagic transudates may occur in the middle ear cavity ¹².

In a broader sense, otitis media encompasses middle ear barotrauma. Both exhibit Eustachian tube dysfunction as a primary cause and display pathological findings of the middle ear cavity. Risk factors for otitis media include upper respiratory tract diseases such as allergic rhinitis, rhinosinusitis, recurrent infections, septal deviation, and chronic adenotonsillar disease.^{13,18,21} The nasal airway has been reported to be an important factor in the etiology of otitis media.^{3,7,24} In addition, Morgagni et al. showed that a previous history of ENT disease may be a predictor of delayed ear pain and ENT abnormalities predict acute middle ear barotrauma.¹⁵ Igarashi et al. also demonstrated that upper respiratory tract infections or mucosal congestion could be predisposing factors for middle ear barotrauma.⁹ Nevertheless, these studies did not provide detailed information regarding specific ENT diseases.

In the present study, concomitant nasal symptoms and nasal endoscopic findings were found to be associated with clinical characteristics of middle ear barotrauma. Among

Table II. Distribution of Severity of Nasal Symptoms in Accordance with the Grade of Middle Ear Barotrauma.

		SEVERITY	NASAL SYMPTOMS [N (%)]					
GRADE	NUMBER OF CASES		STUFFY NOSE	RHINORRHEA	COUGH	SPUTUM	THROAT PAIN	SNEEZE
0	23	0	14 (60.9%)	16 (69.6%)	21 (91.2%)	20 (87.0%)	18 (78.3%)	20 (87.0%)
		1	6 (26.1%)	6 (26.1%)	1 (4.4%)	3 (13.0%)	3 (13.0%)	2 (8.6%)
		2	3 (13.0%)	1 (4.3%)	1 (4.4%)	0	2 (8.7%)	1 (4.4%)
l	5	0	2 (40.0%)	1 (20.0%)	2 (40.0%)	4 (80.0%)	5 (100.0%)	3 (60.0%)
		1	0	4 (80.0%)	2 (40.0%)	1 (20.0%)	0	2 (40.0%)
		2	3 (60.0%)	0	1 (20.0%)	0	0	0
	27	0	15 (55.6%)	16 (59.3%)	22 (81.5%)	19 (70.4%)	24 (88.9%)	25 (92.6%)
		1	3 (11.1%)	6 (22.2%)	3 (11.1%)	5 (18.5%)	3 (11.1%)	0
		2	9 (33.3%)	5 (18.5%)	2 (7.4%)	3 (11.1%)	0	2 (7.4%)
IV	2	0	0	0	1 (50.0%)	1 (50.0%)	1 (50.0%)	2 (100.0%)
		1	0	1 (50.0%)	1 (50.0%)	1 (50.0%)	1 (50.0%)	0
		2	2 (100.0%)	1 (50.0%)	0	0	0	0
Trend Test			P = 0.158	P = 0.104	P = 0.513	P = 0.063	P = 0.338	P = 0.712

			NASAL ENI	DOSCOPY [<i>N</i> (%)]		NASAL ENDOSCOPY [N (%)] DEVIATION OF NASAL SEPTUM	
GRADE	NUMBER OF CASES	SEVERITY	HYPERTROPHY OF TURBINATE (0-2)	NASAL DISCHARGE (0-3)	STATUS		
0	23	0	3 (13.0%)	15 (65.2%)	None	21 (91.3%)	
		1	11 (47.8%)	7 (30.4%)	R-sided	2 (8.7%)	
		2	9 (39.2%)	1 (4.4%)			
		3		0	L-sided	0	
1	5	0	0	0	None	3 (60.0%)	
		1	2 (40.0%)	4 (80.0%)	R-sided	2 (40.0%)	
		2	3 (60.0%)	1 (20.0%)			
		3		0	L-sided	0	
	27	0	1 (3.7%)	9 (33.3%)	None	19 (70.4%)	
		1	8 (29.6%)	11 (40.8%)	R-sided	6 (22.2%)	
		2	18 (66.7%)	6 (22.2%)			
		3		1 (3.7%)	L-sided	2 (7.4%)	
IV	2	0	0	0	None	2 (100.0%)	
		1	0	0	R-sided	0	
		2	2 (100.0%)	2 (100.0%)			
		3		0	L-sided	0	
Trend Test			P = 0.025	P = 0.004		P = 0.177	

Table III. Distribution of Severity of Nasal Endoscopic Findings in Accordance with the Grade of Middle Ear Barotrauma

nasal symptoms, stuffy nose (45.6%) and rhinorrhea (42.1%) were relatively common in cases with middle ear barotrauma. Regarding nasal endoscopic findings, most pilots demonstrated hypertrophy of the inferior turbinate (93.0%) and almost two-thirds (57.9%) exhibited increased nasal discharge, while the prevalence of combined septal deviation was correspondingly lower. In addition, a correlation between the

severity of nasal endoscopic findings (turbinate hypertrophy and pathological nasal discharge) and the grade of middle ear barotrauma was verified in the present study (P < 0.05). However, both nasal symptoms and endoscopic findings showed no definite relation to relapse. The prior incidence of chronic rhinosinusitis (7.8%) or allergic rhinitis (3.9%) was low in this study. Furthermore, only two of four allergic subjects dis-





played acute exacerbation of allergic rhinitis, while the other two showed no related changes in allergic rhinitis. Acute alterations of the nasal airway during flight seem to be more strongly related to middle ear barotraumas than chronic nasal disease.

The authors also described the grade of middle ear barotrauma using Teed's classification. This classification is concise and reflects the prognosis of middle ear barotrauma.²³ However, it does not provide sufficient data about the severity of tympanic retraction, so its use leads to ambiguity in cases with both retraction and redness of the affected eardrum. Therefore, the authors suggest a modification of Teed's classification as follows: Grade I (mild retraction of the tympanic membrane with redness) and Grade II (moderate retraction of the tympanic membrane and total hyperemia). Grade 0, Grade III, and Grade IV



Fig. 4. Scatterplot of duration and grade of middle ear barotrauma, indicating a significant correlation (T = 11.503, df = 1, P = 0.001).

remain the same as the original classification. Further investigation of middle ear barotrauma using this modified Teed's classification is needed.

The duration of middle ear barotrauma might be considered the most important concern for student pilots. The longer their flight training was interrupted, the worse their achievement was in training missions. Accordingly, student pilots with a long period of grounding might drop out of flight-training programs. The mean disease duration was 6.8 d. Fortunately, 43 cases (75.4%) improved within a week, while 49 cases (86.0%) resolved within 10 d without sequelae; 16 cases (28.1%) were completely resolved within 2 d. The cases that improved within 2 d showed less severe stuffy nose (T = 4.615, df = 1, P = 0.032) and rhinorrhea (T = 4.1078, df = 1, P = 0.043) in comparison with cases lasting a week or more. In addition, hypertrophy of the inferior turbinate (T = 21.066, df = 1, P < 0.001) and nasal discharge (T = 12.056, df = 1, P = 0.001) on nasal endoscopy were also less severe in the group with shorter symptom duration. Additional attempts to identify factors contributing to the duration of middle ear barotrauma are necessary in well-designed, larger-scale studies.

The major limitation of the present report is that it did not include otology tests such as pure tone audiometry or tympanometry. Second, no further objective method to demonstrate nasal resistance such as acoustic rhinometry or rhinomanometry was applied in this research, as these tests are difficult to perform before each flight for all subjects. In addition, most aerospace medical corps in the flight wing of the Republic of Korea Air Force did not possess the test equipment needed due to budgetary restrictions and a lack of trained technicians. Complementary studies with these parameters would provide more information about middle ear barotrauma. Questionnaires regarding subjective nasal symptoms and examinations with portable nasal endoscopy are simple and easy to perform before flights. Additional prospective cohort studies are required to evaluate the combination of subjective nasal symptoms and objective nasal endoscopic findings as predictors for middle ear barotrauma.

In conclusion, a stuffy nose and rhinorrhea were relatively common symptoms in generally healthy student pilots who sustained middle ear barotrauma. Most subjects also demonstrated abnormal nasal endoscopic findings such as turbinate hypertrophy or pathological nasal discharge. Subjective nasal symptoms and endoscopic findings were related to the grade and duration of middle ear barotrauma. Questionnaires regarding subjective nasal symptoms and examination with portable nasal endoscopy may be useful for predicting middle ear barotrauma prior to flight training. The majority of cases of middle ear barotrauma resolved within a week; however, some subjects experienced relapse or symptom duration of even a month or more.

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